ON CRYSTALLINE SCHISTS.[1]

I.

§ 1. AS a preliminary to the study of the schistose or stratiform crystalline rocks, it is desirable to consider the wider question of the origin of crystalline rocks in general, which are often named *Primary* or *Primitive Rocks* to distinguish them from those derived therefrom by mechanical or chemical disintegration. The designation of "crystalline rocks" is defective, inasmuch as we find, associated with masses having a right to this title, and geologically confounded with them, other rocks, such as serpentine, obsidian, perlite, and others, which are not crystalline in character, but colloidal, or, to use the designation of Breithaupt, porodic. The primary rocks, then, including both crystalline and porodic masses, may be divided geologically into three categories:—

(1) Masses more or less distinctly stratiform, including the fundamental granite, gneisses, micaceous and hornblendic schists, and all others formed, according to the views of the Wernerian school, by slow deposition in an aqueous liquid at the earth's surface. These we call INDIGENOUS ROCKS. (2) Masses which have strong mineralogic resemblances with the last, but appear to have been formed by slow deposition among pre-existing rocks, in which they occur as veins or secondary masses, and which we have consequently designated ENDOGENOUS ROCKS. (3) Masses which have resemblances, both mineralogic and geognostic, with the endogenous rocks, but are distinguished therefrom by the fact that they appear to have attained their present position not by slow deposition, but as the result of displacements which took place while they were in a more or less liquid or plastic state. These masses, which we designate EXOTIC ROCKS, are, as we shall endeavour to show, to be regarded (whatever their geological age) either as more or less modified portions of the original plutonic material of the globe, or as displaced portions of indigenous or endogenous rocks, and thus in either case belong to the primary class.

§ 2. Without taking into account those who, like Lehmann in the last century, maintained that the indigenous crystalline masses, which he called primitive rocks, were created as we now see them, we may say that the geologists of our own time are divided into two classes: those who admit for the indigenous rocks (1) an igneous or plutonic origin, (2) an aqueous or neptunian origin. Among the plutonists properly so called there are, moreover, two schools, one of which regards the foliated structure which characterizes the crystalline schists as due to the lamination of an igneous mass exposed to strong pressure during its extrusion through the already solidified terrestrial crust. For this school, in fact, the crystalline schists, not less than the granites, the trachytes, and the basalts, are eruptive rocks. This manner of explaining the origin of the crystalline schists, advanced by Poulett Scrope in 1825, and since frequently resuscitated, we have named the *exoplutonic* or volcanic hypothesis. For the other plutonist school, these same crystalline schists are the products of the consolidation, beneath a crust already formed by superficial cooling, of the igneous matter of the globe; the schistose structure being the result either of currents established in the still liquid and heterogenous material, or of a segregation therein during crystallization. To the views of this second plutonist school we have given the name of the *endoplutonic* hypothesis.

§ 3. The neptunists are also divided into several schools. Werner and his disciples believed that the crystalline rocks, both granitic and schistose, had been successively deposited from a universal ocean, which they imagined to have been a chaotic liquid holding in solution the elements of all the primitive rocks. We have called this derivation by slow crystallization from a primordial liquid chaos, the *chaotic* hypothesis. In this purely neptunian hypothesis, the action of a heated interior of the earth did not enter, but certain plutonists, admitting this notion, have imagined a *thermochaotic* hypothesis. This was advanced by Poulett Scrope, in 1825, as the complement of his exoplutonic hypothesis, and subsequently sustained by De la Beche and Daubrée.

Another neptunist school, which also held plutonic views, was that of Hutton, who supposed that the crystalline rocks now known to us have been formed by the consolidation and crystallization, through the agency of internal heat, of sediments arranged by water at the bottom of the seas, these sediments being the detritus either of endoplutonic or of exoplutonic rocks. The defect of this explanation, which we call the *metamorphic* hypothesis, is that it does not take into account the chemical changes suffered by most silicated mineral species during the process of disintegration of the crystalline rocks and their conversion into sands and clays. The production of species such as the feldspars, the micas, hornblende, &c., as the result of a re-crystallization of sediments which do not contain the elements of these minerals, demands the additional supposition of chemical changes brought about either by substitution or by simple addition. In this manner, attempts have been made to explain supposed transformations, often very surprising, among which may be noted, not only the conversion of siliceous and argillaceous sediments into feldspathic and hornblendic rocks, but that of limestones into gneiss and other feldspathic and siliceous rocks, and also the conversion of these, as well as of diabases and diorites, into serpentine, or into crystalline limestone. This view, which we have called the *metasomatic* hypothesis, is, in the minds of many geologists, confounded with the metamorphic hypothesis of Hutton, of which it is, to a certain extent, the indispensable complement.

§ 4. Of all these hypotheses, that of Werner, which considered the primæval chaos as a watery liquid holding in solution the materials necessary for the formation of all the crystalline rocks, appears to us the one nearest the truth. It is certain, however, that in the present state of our chemical knowledge we cannot admit the simultaneous existence of all these materials in solution, even at the elevated temperature supposed by the thermochaotic hypothesis. We have, however, endeavoured to reconcile with known facts the view that a great part of all the primary rocks, including both the granites and the crystalline schists, have at one time been in the state of aqueous solution, through the action of processes which have operated without cessation from the Primary period. This explanation, which we have elsewhere set forth in detail, after a critical examination of the other hypotheses already mentioned, we have named the *crenitic* hypothesis, from the Greek κρήνη, fountain or spring.

Starting from the conception of a liquid globe of igneous origin, the solidification of which commenced at the centre, we find in its exterior portion—the last to solidify—the source of all the known terrestrial rocks; in other words, the veritable mineral protoplasm. This material we suppose to have been, from the time of its superficial cooling, exposed to the action of water and the atmospheric gases, while it was at the same time heated from below by the internal warmth, and penetrated to a greater or less depth by watery solutions. These, under the influence of the existing thermal differences, must have established a circulation between the surface and the deeper portions of the protoplasmic mass, which, as the result of crystallization and cooling, had already become porous. From the abundant outflow of thermal waters thus produced is derived the name "crenitic," given alike to the mineral deposits formed by them and to the present hypothesis. The action of these waters, removing from the protoplasmic material silica, alumina, and potash, and bringing to it at the same time lime, magnesia, and soda, must have necessarily altered by degrees the composition of this porous mass, heated from below, penetrated by aqueous solutions, and rendered more or less plastic in parts. In the changing mass, moreover, took place processes of crystallization, followed by partial separations determined by differences in specific gravity between the species thus formed. In this way were produced various types of plutonic rocks, which may justly be called Primary, since they are more or less modified portions of the original protoplasmic material.

§ 5. The dissolving action of the circulating waters continued without interruption from a very remote period in the history of the globe, and, extending eventually to depths equal to very many kilometres, while giving rise to the immense thickness of crenitic rocks which cover the surface of the protoplasmic mass, must necessarily have effected a great diminution therein. This decrease of volume beneath the crenitic covering must have resulted in movements giving rise to the more or less marked corrugations everywhere met with in the earlier layers of the crenitic envelope—movements which have continued, though with decreasing force, through all geological periods. Moreover, the accumulated weight, alike of crenitic deposits and of mechanical sediments, would bring about at length the displacement, in a plastic state, of portions of the primitive mass, as well as of parts of the crenitic layers themselves, in the form of eruptive rocks, forming not only *plutonic* masses, but those which we have designated as *pseudoplutonic*--that is to say, masses of crenitic origin which present the geognostic characters of plutonic rocks. Such are apparently the trachytes and the truly eruptive granites. Eruptions of these two classes of rocks seem to have been rare in the more ancient periods, but in later times they have played an important part in the transfer of mineral matters from the depths to the surface of the globe, while at the same time the crenitic activity has progressively decreased. Without questioning the effect of the slow contraction through the secular cooling of the heated anhydrous and solid nucleus of the globe, we believe that the diminution of volume of its more superficial and hydrated portions by the crenitic process, as well as by plutonic eruptions, has played a very important part in geological dynamics.[1]

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[1] Translated by the author from his essay on "Les Schistes Cristallins," presented to, and published in French by, the International Geological Congress in London, 1888. The footnote to § 5 has been added in translating

§ 6. According to the hypothesis just set forth, it follows that the production alike of the crenitic and the plutonic rocks, as the result of the transformations of a primitive material presumed to be of igneous origin, has been subjected to constant, regular, and definite laws. It shows, in fact, a mineralogical evolution which has determined the order, the composition, and the succession of the crenitic masses of the terrestrial crust, as well as the composition of the plutonic masses of the various geological periods. In the study of the successive groups of crenitic rocks we must take into account the intervention in the crenitic process alike of the soluble and the insoluble products of the aërial decomposition both of more ancient crenitic rocks and of plutonic masses, as well as the effects, both direct and indirect, of the products of organized beings. It results from the influence of all these secondary agencies which have intervened in the course of the crenitic process, that the fundamental granite, as the most ancient crenitic rock, presents characters of uniformity and of universality which do not reappear in the less ancient crenitic terranes. These, in fact, already begin to show indications of a passage to the new order of things, and were thus, in the language of the Wernerian school, called Transition rocks.

As a farther result of this mineralogical evolution in the history of the crenitic rocks, we find that certain aluminiferous silicates rarely met with at a given period, at length become more abundant and finally predominate. For this reason it follows that in the mineral kingdom, as in the organic kingdoms, generalizations which have for their object chronological classifications, should be founded upon the character of a group taken in its integrity, and not upon the characters of exceptional species. For the rest, it is to be remarked that non-aluminiferous species, such as the protoxyd-silicates, quartz, carbonate of lime, and oxides of iron are found, with small variations, in the crenitic masses, whether indigenous or endogenous, alike of earlier and of later periods.

It is evident that the operations of solution and of aqueous deposition, as well as those of decomposition and sub-aërial decay, went on in the Primary and Transition periods under geographical conditions which did not differ greatly from those of the Secondary and Tertiary periods. The marks of erosion, of contemporaneous movements, and of deposition in discordant stratification are met with at different horizons in the indigenous terranes of the Primary as well as in those of the Secondary ages; offering in both cases local and accidental interruptions of the normal order of mineralogical development.

§ 7. The various granitic, quartzose, and calcareous veinstones, including metalliferous lodes, not less than the veins and geodes of zeolitic minerals, are examples of endogenous masses formed by the crenitic process. The production of zeolites and of other silicates by the action of thermal waters, and the formation of zeolitic species in the deep-sea ooze, are examples of the same crenitic action continued to our own time. As is shown by the studies of the action of our modern thermal springs, the surrounding solid matters co-operate with those in solution in the production of new mineral species. We must not overlook the part which is often played by infiltrating waters in producing local transformations in sediments, thereby giving rise to the production of crystalline species in the midst of detrital rocks. Pressure alone appears in certain cases to produce similar results, all of which cases are often insisted upon in support of the application of the metamorphic and metasomatic hypotheses to the origin of the primary rocks.

The granitic veins, composed essentially of orthoclase and quartz, which are found not only among gneisses and mica-schists, but among basic plutonic rocks alike of Palæozoic and of Mesozoic age,[1] help us to understand the conditions which in times of greater crenitic activity gave rise to the production of the gneisses and the fundamental granite, both of which, according to our hypothesis, are essentially neptunian and crenitic in their origin. These same indigenous and endogenous crenitic rocks have furnished the greater part of the materials for the Secondary rocks. We have already indicated concisely, in § 4, our explanation of the origin of the true plutonic rocks, as the result of modifications which have taken place in the midst of the protoplasmic mass.

§ 8. We must not lose sight of the important part played by water in plutonic and volcanic phenomena, nor the fact that it can exist under strong pressure, at high temperatures, in combination with silicated rocks. From this union there result hydrated compounds, which are more fusible than the anhydrous rocks, and which are decomposed in the transformations that take place during the cooling, with diminution of pressure, which accompanies the eruption of these materials. The water thus set at liberty may be disengaged in the form of vapour, and with it certain other volatile matters which are met with in volcanic emanations. In other cases, however, under a high pressure still maintained, and at a temperature above the critical point of vaporization, the water may be liberated in the state of a dense polymeric vapour, holding in solution, in accordance with late observations, mineral matters, which, through cooling, are at length deposited either from the vapour itself or from the liquid resulting from its condensation, in the form of crystalline species. Superheated aqueous vapours may thus play a part closely akin to that of thermal waters, and one which must be regarded as itself belonging to the crenitic process.

The greater part of the questions here noticed have already been discussed in detail by the author in his volume entitled "Mineral Physiology and Physiography" (Boston, 1886), especially in the three chapters on the Origin, the Genetic History, and the Decay of Crystalline Rocks (pp. 68–277.)

II.

§ 9. In another chapter of the volume just mentioned the author treats of the History of Pre-Cambrian Rocks (pp. 402–25), and endeavours to resume in a few pages the results of his attempts through a period of forty years to arrive at a subdivision and a nomenclature of these terranes, which comprise both the Primary and the Transition systems of Werner. It must suffice for the present to indicate in a succinct manner the conclusions already reached.

I. LAURENTIAN.—Under this name, proposed and adopted by the author in 1854, is included the ancient gneissic terrane met with in the Laurentide and the Adirondack Mountains, as well as in parts of the great Atlantic belt, and in the Rocky Mountains in central North America. To this same series the author has also referred the similar gneisses of Great Britain and of Scandinavia, as well as the ancient or central gneiss of the Alps. Beginning with our first studies in Canada in 1847, we indicated the existence in this ancient gneissic system of two subdivisions, the lower being described as consisting of granitoid gneiss (to be confounded with the fundamental granite), to which succeeds (in discordant stratification) another gneissic series, also granitoid, and frequently hornblendic, with which are intercalated quartzites and crystalline limestones, often with serpentine. These two subdivisions, which we may provisionally call Lower Laurentian and Upper Laurentian, have been described respectively as the Ottawa gneiss and the Grenville series. To prevent any misconception, it should be noted that the name of Upper Laurentian was for a time given by Logan to the terrane subsequently designated Labradorian, and afterwards Norian. It is therefore by a mistake that some have wished to retain as the designation of the upper division of the Laurentian terrane, the name of Middle Laurentian.

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[1] Besides the removal of all the silica and alumina found in the crenitic rocks must be added the diminution of porosity in the protoplasmic mass and the probable formation of more condensed species than those originally contained therein.

[1] We have elsewhere described the granitic veins inclosed in the diabases which themselves traverse the Ordovician limestones of Montreal in Canada. These veins, having sometimes a thickness of three decimetres, are coarsely crystalline and drusy, and, besides quartz and orthoclase, contain, as accidental minerals, sodalite, nephelite, cancrinite, amphibole, acmite, biotite, and magnetite. Veins composed essentially of pink orthoclase and quartz, often accompanied by zeolitic minerals, are found in similar conditions inclosed in the diabases which are contemporaneous with the Mesozoic sandstones of Hoboken, near New York. In both cases the endogenous and crenitic origin of the granitic veins does not admit of any doubt. See for details the author's "Mineral Physiology and Physiography" (Boston, 1886), pp. 121–37.

II. NORIAN.—The terrane thus designated by the author in 1870 is composed in great part of those straliform rocks having a base of anorthic feldspars, to which has been given the name of norite. This terrane, however, includes intercalated strata of gneiss, of quartzite, and of crystalline limestone, all of which resemble closely those of the Upper Laurentian. These norite rocks, which are sometimes called gabbros, are not to be confounded with the very distinct gabbros of the Huronian terrane, nor yet with certain plutonic rocks having with them certain mineralogical resemblances. The facies of the norites serves to distinguish them.

III. ARVONIAN.—This terrane is composed in great part of petrosiliceous rocks, which pass into quartziferous porphyries. With them, however, are intercalated certain hornblendic rocks, sericitic schists, quartzites, oxides of iron, and, more rarely, crystalline limestone. This terrane, indicated for the first time as distinct by Dr. Henry Hicks, in Wales, in 1878, and named by him, is regarded by Mr. Charles Hitchcock as constituting in North America the lower portion of the Huronian.

IV. HURONIAN.—This name was given by the author in 1855 to a terrane already recognized in North America, where it rests in discordant stratification either upon the Laurentian gneiss or upon the Arvonian petrosilex. It includes, besides quartzose, epidotic, chloritic, and calcareous schists, masses of serpentine, and of lherzolite, together with euphotides, which represent herein the norites of the Norian terrane, often confounded with them under the common name of gabbro. This Huronian terrane is greatly developed in the Alps, where it constitutes the series of the greenstones or *pietre verdi*.

V. MONTALBAN.—The studies of von Hauer in the Eastern Alps, published in 1868, and those of Gerlach on the Western Alps, published in the year following, agree in recognizing in these regions two gneissic terranes—namely, an older or ancient central gneiss, and a younger or recent gneiss; this last, which is petrographically very distinct from the old gneiss, being accompanied by micaceous and hornblendic schists. The studies of Gastaldi, published in 1871, and those of Neri, in 1874, while confirming the results of von Hauer and of Gerlach, furnish us with further details respecting these terranes and their lithological characters. It should here be remarked that all of these observers appear to agree in placing the horizon of the *pietre verdi* (Huronian) between the ancient gneiss (Laurentian) and the recent gneiss.

Before becoming acquainted with the first results of these observers, the writer, from his own studies in North America, was led to precisely similar conclusions, and in 1870 announced the existence of a series of younger gneisses very distinct from the old Laurentian gneisses, and accompanied by crystalline limestones and by micaceous and hornblendic schists. To this younger terrane, on account of its great development in the White Mountains of New Hampshire, he gave in 1871 the name of Montalban. This series appears to be identical with the younger gneiss of the Alps; the so-called Hercynian gneisses and mica-schists of Bavaria; the granulites, with dichroite-gneiss, mica-schists, and lherzolite of the Erzgebirge in Saxony; and similar rocks in the Scottish Highlands. The Montalban terrane in North America contains not only crystalline limestones, but beds of lherzolite and of serpentine, resembling in this respect the Huronian and the Laurentian. It is in this series, in North America at least, that are found the chief part of the veins or endogenous masses of granite, which carry beryl, tourmaline, and the ores of tin, of uranium, of tantalum, and of niobium.

Gastaldi, in an essay published in 1874, declares that "the *pietre verdi* properly so called" is found between "the ancient porphyroid and fundamental gneiss" and "the recent gneiss, which latter is finer-grained and more quartzose than the other." This younger gneiss he also describes as a gneissic mica-schist, and as a very micaceous gneiss passing into mica-schist, and often hornblendic; the two gneissic series being, according to him, easily distinguished the one from the other. To these two divisions, superior to the ancient gneiss—that is to say, the true *pietre verdi* and the younger gneiss—Gastaldi adds a third division, still more recent. This highest division contains considerable masses of strata called by him argillaceous schists, and otherwise lustrous, talcose, micaceous, and sericitic schists. Associated with these are also found quartzites, statuary and cipolin marbles, with dolomite, karstenite, and sometimes hornblendic rocks and serpentines, the presence of which in this division, and also among the recent gneisses, as well as "in the *pietre verdi* proper," was regarded by Gastaldi as justifying the name of "the *pietre verdi* zone," often given by him to the whole of this tripie group of crystalline schists, which he recognized as younger than the central gneiss.[1]

VI. TACONIAN.—This third division, to which Gastaldi did not give a distinctive name, has, as is well known, a very interesting history in Italian geology. A terrane having the same horizon and the same mineralogical characters is found developed on a grand scale in North America, where it includes quartzites, often schistose, and sometimes flexible and elastic, with crystalline limestones yielding both statuary and cipolin marbles. It also contains deposits of magnetite and of hematite, as well as important masses of limonite, which is epigenic in some cases of pyrites, and in others of chalybite, two species which form, by themselves, large masses in the undecayed strata. This same terrane contains, moreover, roofing-slates, as well as lustrous unctuous schists, ordinarily holding damourite, sericite, or pyrophyllite, but including, occasionally, chlorite, steatite, and hornblendic rocks with serpentine and ophicalcite. We also find among these schists, which are met with at several horizons in the terrane, layers which are visibly feldspathic, with others of ill-defined character, which, however, are converted into kaolin by sub-aërial decay. These same schists furnish remarkable crystals of rutile, and also tourmaline, cyanite, staurolite, garnet, and pyroxene. This terrane, which, moreover, appears to be diamond-bearing, was described in 1859 by the late Oscar Lieber, under the name of the Itacolumitic group. Eaton already, in 1832, had placed the quartzites and the limestones, which form the lower members of this group, in the Primitive division. The argillites in the upper part of the group were regarded as the inferior member of his Transition division, and were, according to him, overlain unconformably by the fossiliferous graywacke (First Graywacke), made the upper member of this same Transition division. In 1842, Ebenezer Emmons included in what he then named the Taconic system the whole of this crystalline series, to which he added the graywacke; but in 1844 he separated this latter, in which he had meanwhile found a trilobitic fauna, and gave it the name of Upper Taconic; the inferior and crystalline portions being the Lower Taconic. Many years of study have shown me that this upper division is entirely independent of the Lower Taconic, with which the fossiliferous graywacke series is found in contact only in certain localities, while in many others it rests directly upon more ancient crystalline terranes. Seeing, morever, that the Lower Taconic is found without this graywacke, in a great number of localities, from the Gulf of St. Lawrence as far as Alabama to the south, and as far as Lake Superior to the west; and recognizing also the fact that the Upper Taconic is really a part of the Cambrian (as was avowed by Emmons himself in 1860), the author proposed in 1878 to limit the use of the term Taconic to the crystalline infra-Cambrian series which forms the Lower Taconic of Emmons and the Itacolumitic group of Lieber, and to call it the Taconian terrane.

The history of the various attempts made by the partisans of the metamorphic school to establish a more recent origin for the Taconian is a curious one. Various American geologists, adopting for the most part stratigraphical arguments, have successively referred it to the Cambrian, Ordovician, Silurian, Carboniferous, and Triassic horizons. It is, however, to be noted that these same geologists have also maintained the Palæozoic age of the greater part of the other crystalline terranes of North America, comprising the Montalban, the Huronian, the Arvonian, and a part of the Laurentian itself. The want of any conception of the principle of mineralogical development in the history of the crystalline schists, conjoined with the difficulties arising from the stratigraphical complications met with at many points along the eastern border of the great North American Palæozoic basin, has helped to confirm the belief of many American geologists in the hypotheses of the metamorphic and metasomatic schools.[2]

§ 10. The mineralogical resemblances which exist between the various crystalline terranes above mentioned are easily recognized.

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[1] This question is discussed at length by the writer ("Mineral Physiology and Physiography," pp. 457–96) in a study of the geology of the Alps and the Apennines, and of the serpentines of Italy. See also his paper on "Gastaldi and Italian Geology," containing a hitherto unpublished letter from Gastaldi, in the *Geological Magazine* for December 1887.

[2] The reader who wishes to follow this question will find it discussed with much detail in the volume already cited "Mineral Physiology and Physiography" (pp. 517–686) under the title of "The Taconic Question in Geology." It is also treated, with some new facts, in the *American Naturalist* for February, March, and April, 1887, in an article entitled "The Taconic Question Restated."

The type of rocks characterized by orthoclase, appearing in the fundamental granite and the granitoid gneisses of the Laurentian, is again found in the quartziferous porphyries of the Arvonian, in the Montalban gneisses, and, though less distinctly, in the feldspathic rocks of the Taconian. The non-magnesian micas, rare in the fundamental granite and the Laurentian gneisses, appear abundantly in the Montalban gneisses and mica-schists, as well as in the lustrous schists which are found in the Huronian and the Taconian, and which predominate in the latter. It is further to be remarked that the simple silicates of alumina, such as andalusite, cyanite, fibrolite, and pyrophyllite, as yet unknown in the more ancient terranes, are abundant in the Montalban, and are also found in the Taconian. At the same time, crystalline limestones, oxides of iron, and calcareous and magnesian silicates, are met with in every terrane above the fundamental granite.

The chemical and mineralogical differences between these various terranes are more remarkable than the resemblances, a fact which, however, has not prevented some observers from confounding the younger with the older gneisses. Again, the resemblances between the Huronian and Taconian terranes led the late Prof. Kerr, in North Carolina to refer the latter terrane to the Huronian. Moreover, in the vicinity of the Lakes Superior and Huron, where we find alike Laurentian, Norian, Huronian, Montalban, and Taconian, the outcrops of this last were confounded with the Huronian by Murray and by other observers. In 1873, however, the author, distinguishing between the two, gave to the Taconian in this region the provisional name of the Animikie series. It was not until later that he recognized the fact that this series, which is here found in certain localities resting unconformably upon the Huronian, is no other than the Taconian. Emmons, on the contrary, who had long known the existence in this region of what he called the Lower Taconic, believed that the terrane to which the author gave, in 1855, the name of Huronian, was identical with this same Lower Taconic or Taconian. The differences between these two terranes in the basin of Lake Superior, first noted by Logan and later by the author, are clearly brought out by the recent studies of Rominger.

Upon all these different terranes, including the Taconian, there rests in discordant stratification in this region a vast series of sandstones and conglomerates, with contemporary basic plutonic rocks, the whole remarkable by the presence of metallic copper. This series, which had been alternately confounded with the Huronian and the Taconian on the one hand, and with the trilobitic sandstones of the Cambrian on the other, was for the first time separated by the author in 1873, under the name of the Keweenaw group, a term changed by him in 1876 to that of the Keweenian terrane. It still remains to be decided whether this series, upon which rest unconformably these same trilobitic sandstones, should form a part of the Cambrian, or should constitute a distinct terrane between the Taconian and the Cambrian.

§ 11. In submitting to his colleagues of the International Geological Congress this summary of his conclusions, based on over forty years of study, the author takes the liberty to state that the notions here advanced as to the origin, the chemical and mineralogical history, the subdivision, and the nomenclature of crystalline rocks, are for the most part the generalizations of a single observer. He now offers them as a first attempt at a classification of the indigenous rocks, and at the same time as an exposition of his crenitic hypothesis, and of the mineralogical evolution of the globe, which he conceives to have determined the succession and the chemical nature of the masses which he has named crenitic, as well as those of plutonic masses. He feels at the same time that his work is far from complete, and that to others must now be left the task of correcting and finishing it.

As a large part of these results, so far as regards geognostic classification, appeared for the first time in the Reports of the Geological Survey of Canada, the author may be permitted to say, in closing, that the first publications made by that Geological Survey on the crystalline rocks of Canada—that is to say, the reports of progress for the years 1845 and 1846, were prepared by him, and published in 1847, from the notes and the collections made by Logan and by Murray in the two years previous. Moreover, all the statements relating to the mineralogy, the lithology, or the chemical composition of the rocks of Canada, which are found in the official reports from 1847 to 1872, when the author resigned his position as a member of the Geological Survey of Canada, were written by him or under his personal direction.

T. STERRY HUNT.

SOME QUESTIONS CONNECTED WITH THE PROBLEM PRESENTED BY THE CRYSTALLINE SCHISTS, TOGETHER WITH CONTRIBUTIONS TO THEIR SOLUTION FROM THE PALÆOZOIC FORMATIONS.[1]

THE question of the "crystalline schists" still presents so many unsolved difficulties, and the views of contemporaneous fellow-workers diverge herein so widely, that an attempt at unanimous agreement on the points at issue must at present be regarded as premature. This assuredly does not prevent our taking counsel together, interchanging observations, and endeavouring to gain solid ground, whence a future solution can be aimed at. Each geologist will approach such a consultation in a way differing in accordance with his own experience.

I can only contribute experience gained by the study of the metamorphic crystalline schists, belonging to the *Palæozoic* formations, that have been proved to have resulted from the action of contact or dynamic metamorphism on eruptive or stratified rocks, the latter including the tuffs. The *direct* application of this experience to *all* Archæan crystalline schists appears to me premature—*i.e.* rather a *thema probandum* than *probatum*. Doubtless there are cases—as, for instance, in the so-called flasergabbros or zobtenites, which, apparently, must be regarded as quite analogous to the alteration of the diabases in the Palæozoic formations. Indeed, the same essential features which Lehmann has described in the development of the Saxon "flasergabbros" have been demonstrated by Teall in the Lizard gabbros, G. H. Williams in the Baltimore gabbros, and Hans H. Reusch in Norway. But Hans H. Reusch also mentions *bedded gabbros*[2] as well as eruptive flasergabbros, differing thus from Lehmann; while Credner and Roth appear by no means willing to concede all that is contained in Lehmann's book. This fundamental difference must, however, be noticed: Lehmann holds the Archæan schists half for metamorphosed sediments, half for interbedded or injected eruptive rocks; and although I cannot agree with or follow Lehmann in every detail (and, above all, lay more stress upon the altered tuffs), still on the whole I can but support him in this view. Roth, on the other hand, holds all the Archæan crystalline schists—limestones, quartzite, gneiss, mica-schist, amphibolite, &c.—for *schistose, plutonic* (only in form not eruptive) rocks (*Erstarrungskruste*); finally, Credner holds the majority of the crystalline schists, including granite-gneiss and flaser-gabbro, for the *normal stratified* sediments of a primæval ocean, their crystalline nature being essentially not due to metamorphism.

I have dwelt thus at length on this point in order to demonstrate that there exist numerous controversies even on those questions that admit of solution by reason of the *most undoubted pseudomorphic changes* (hornblende after diallage, hypersthene, augite; zoisite, epidote, actinolite, quartz, albite after lime-soda feldspar), and by reason of the presence of the *original eruptive structure.*

My stand-point is identical with that expressed by Carl Friedrich Naumann in the following words: *My task above all else is to study the metamorphism, with respect both to substance and to structure, of the fossiliferous sediments and the eruptive rocks, together with the tuffs intercalated therein.* Much has already been done, especially with respect to contact-metamorphism, which is more sharply defined than regional or dynamic metamorphism. There remains, however, much to answer, especially as the primary structures of original schistose eruptive rocks and the structure and substance of certain very common sedimentary rocks (as, for instance, the greywackes, the so-called greywacke-schists, or the majority of the tuffs) are still too little known to afford a firm basis for the study of metamorphic processes.

Still the detailed solution of the following question would be of no little value for the study of the Archæan schists:—

(1) What material agreement or difference exists between the

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[1] "Einige Fragen zur Lösung des Problems der krystallinischen Schiefer, nebst Beiträgen zu deren Beantwortung aus dem Paläozoicum," von Prof. Dr. K. A. Lossen. "Etudes sur les Schistes cristallins," 1888. Published by the International Geological Congress in London, 1888. (Translated from the German by Dr. F. H. Hatch.)

[2] Giving a somewhat wide meaning to the word "gabbro"; he now says, "dioritic rock," "altered gabbro and diabase." In the Hartz the interesting gabbro-district of Hartzburg presents, among numerous other varieties, some which show layers alternately richer in plagioclase and diallage (bronzite) or present *flaser*-structure with biotite, and possess thus a *bedded-like* but not a true *bedded* parallel structure. These rocks are true eruptive gabbros.